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ABSTRACT

We describe highly generative and affectively powerful classroom activity structures that are made possible by applying new levels of connectivity across diverse hardware platforms. Based on teaching experiments involving core topics in basic algebra (slope-as-rate, linear functions, simultaneous conditions), we examine 3 kinds of activity structures exploiting a common display of student-produced mathematical objects: (1) Construction and sharing of personally meaningful and executable mathematical objects in "mathematical performances", (2) Aggregation and display of student constructions that are systematically varied based on classroom social and/or physical structure, and (3) The Where Am I? aggregation activity structure, where studentsÕ constructions are aggregated in ways that require students to perform careful analyses to "find themselves" in the aggregation. Strong learning achievement pre/post-test results suggest considerable promise in such activities, especially with low-performing students. (Author)

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EXPLORING THE PHENOMENON OF CLASSROOM CONNECTIVITY[1]

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We describe highly generative and affectively powerful classroom activity structures that are made possible by applying new levels of connectivity across diverse hardware platforms. Based on teaching experiments involving core topics in basic algebra (slope-as-rate, linear functions, simultaneous conditions), we examine 3 kinds of activity structures exploiting a common display of student-produced mathematical objects: (1) Construction and sharing of personally meaningful and executable mathematical objects in "mathematical performances," (2) Aggregation and display of student constructions that are systematically varied based on classroom social and/or physical structure, and (3) The *Where Am I?* aggregation activity structure, where students' constructions are aggregated in ways that require students to perform careful analyses to "find themselves" in the aggregation. Strong learning achievement pre/post-test results suggest considerable promise in such activities, especially with low-performing students.

Context and Aims of the Sstudy

We are currently investigating the impacts and potentials of recent advances in connectivity technology in grades 7-9 mathematics classroom, particularly linking diverse hardware platforms such as the TI-83+ graphing calculators and larger computers.

The work builds on earlier SimCalc research (for summary see Roshelle et al., 2000) which aimed to democratize access to the Mathematics of Change and Variation underlying the Calculus (Kaput, 1994) using a variety of new representations, links to simulations and new curriculum materials. The software enables students to interact with animated objects whose motion is controlled by visually editable piece-wise or algebraically defined position and velocity functions. One form of the software has been developed for the TI-83+ (Calculator MathWorlds) and the other is a cross-platform Java application (Java MathWorlds) which exploits higher screen resolution, with the ability to pass MathWorlds documents between the two platforms—see www.simcalc.umassd.edu for further details. The new ingredient is classroom connectivity that enables students to share mathematical functions across diverse hardware platforms and teachers to collect, aggregate on a common classroom display, and otherwise work with students' constructions on the teacher's workstation, as well as to distribute functions to the students. Hence we combine the two root affordances of the computational medium, representation and communication.

In this paper, we describe the phenomenological space of a SimCalc connected mathematics classroom that arises from preliminary studies in the Spring and Fall Semesters of 2001, and more tightly controlled empirical work currently underway.

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Theoretical Framework

Classroom connectivity (CC) opens a large and richly endowed opportunity space for teaching, learning, assessment and curriculum activity design, a space jointly structured by the structures of mathematics, and the social and physical structures of the classroom in a dialectical relationship (Stroup, et al., these proceedings). The social structure plays a direct role in the structuring of mathematical activities, and vice-versa in a dialectical fashion. In some cases, the interplay of social and mathematical structures lead to an elevation of organization of mathematical structure, as when students organized into groups build functions that vary parametrically across the groups, yielding structured families of functions reflecting the structure of the classroom, an elevation of the organizational structure of the mathematical objects, from functions to families of functions. At the same time, the focus of student attention is likewise elevated to the level of what the group is doing rather than what the individual is doing. In addition, for certain of the activities that we explore, students' personal identities are intimately involved in their building and sharing of mathematical objects in the public space of the classroom. While in this brief paper we focus on teaching and new activity structures, we note that an enormous range of foundational educational issues are raised by CC because the radically increased bandwidth of CC, supporting the direct sharing of mathematical objects such as functions, directly affects the heart of what happens in classrooms, among students and between students and teacher. See our Discussion Group paper with Stroup, et al. (these Proceedings) for further discussion of our theoretical framework.

Technological Connectivity

The prototype Navigator network from TI allows us to connect TI-83+ graphing calculators together. As many as four calculators, including the teacher's calculator, can be physically connected to a hub which wirelessly communicates to an Internet gateway in the classroom that in turn communicates with a remote server. This server acts as an active storage buffer between students and teacher. The teacher can also send and retrieve information and display received information on a standard TI-Viewscreen. This information includes Calculator MathWorlds documents. For example, a student can construct or edit a piece-wise defined position function and send it to the teacher who can then display the function, run its animation, and base a classroom discussion on it using the TI-83+ with ViewScreen.

Since Java MathWorlds can pass, collect and collate students' documents, the teacher can aggregate student constructions on the teacher's computer as well, including constructions produced on a computer rather than a graphing calculator and communicated via a standard computer network using standard intranet protocols. Finally, using the ability to pass MathWorlds documents between the two types of platforms, virtually any mix of the platforms can be used in the classroom (or computer laboratory). Our empirical work increasingly exploits these connectivity options.

Data Sources

The ideas and data below reflect work in three venues, where we collected video data, field notes, and student work, as well as pre-post test data in 2 & 3. The mathematical topics across each venue included slope-as-rate, linear functions, simultaneous conditions, and modeling of linearly changing phenomena in both motion and non-motion contexts. In addition, in 2, we covered the full SimCalc curriculum, which involved rate-accumulation connections across a wide variety of rates of change and modeling contexts using graphical, algebraic and numerical descriptions. A fourth intensive teaching experiment was carried out with high-performing middle school students and which focused on peer-peer applications of connectivity, but will not be reviewed here.

1. We piloted the Navigator system in two local high school Algebra I classes in Spring 01 taught by their regular teacher (a SimCalc-experienced teacher). Topic:
2. We used a more stable form of the system in combination with a teacher workstation in a required year-long course taught by the PI at UMass-Dartmouth for 12 academically weak entering College Freshmen (who mathematically and demographically are comparable to typical urban high school algebra students).
3. We used a mix of calculators and computers in a 5 week Spring 02 after-school course for 35 grade 7-9 students in a second local high school taught by a SimCalc novice teacher from that school and assisted by two other SimCalc novice teachers. This course took place in a computer laboratory.

The first two venues helped generate and prototype activity structures that were then used more intensely in the 3rd. And since the 3rd also included pre-post test data where the majority of items were chosen from a required 10th grade state assessment, we will focus on task-types used in this intervention and follow with a brief summary of the results. Space limitations prevent transcript segments from sessions where these activities were utilized, but annotated video will be offered as part of the PME-NA presentation.

Three Basic Activity Structures

We will illustrate three kinds of activity structures, each of which uses the social space of the classroom, and engages students' identities, in a different way. We will, however, limit the examples to topics associated with linear functions and slope-as-rate.

(1) Creating and Sharing a Personally Meaningful Mathematical Object—Mathematical Performances

This is a relatively simple type of activity, but one that we feel has enormous pedagogical potential because of the ways it taps into adolescent students' personal

experience, their personal identity, their need for recognition, and their creativity in expressing their unique personal experience. It also serves to focus class attention, which leads to opportunity for intense follow-up engagement by the teacher to exploit issues raised, for pedagogical and curricular purposes. We provide an example that was used across all venues using the TI-83+ version of MathWorlds and, with links to instructional material as well as graphics and student scripts illustrating the activity.

Create an Exciting Sack Race That Ends in a Tie (Slope-As-Rate-of-Change)

We provide students the graph of a constant velocity position vs. time function which controls the (horizontal) screen motion of one object (A, the "car-like box" Above), which has the given constant velocity position vs. time graph in Figure 1 - A travels for 10 seconds at 2 m/sec. With the short stub of a starter-graph for B, we ask the student (1) to write a race-script for an "exciting race" with A; (2) to create a position vs. time graph for B that enacts the race; and (3) Send the race-document to the teacher who replays the race in front of the class on a large-screen display while the student author of the race "calls the race" by reading their narrative script as it runs.

We have seen both a large variety of uniquely personal student creations in response to this task and clear indicators of the "mathematical performance" aspects of the task—for example, in most cases, the classroom audience breaks into spontaneous applause when the race and story are complete. We offer a teacher's model race for simplicity's sake, and, in order to give a sense of how this activity is introduced to students, we embed the race-story in the form of directions to a teacher who is introducing the activity to a class. The teacher raises issues of steepness of line segments, zero slope, negative slope as well as intersection of function graphs and their interpretation as simultaneous position.

Imagine the teacher adding and adjusting one segment at a time (by stretching left or right and "tilting" it to adjust its slope) to produce the composite race shown in Figure 2 while asking a series of questions as follows. (i) Assume that B gets off to the

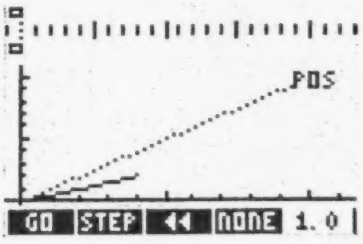

Figure 1.

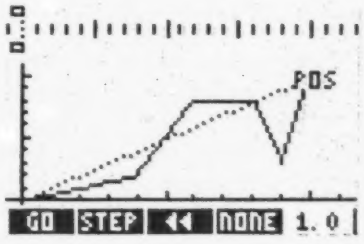

Figure 2.

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slow start as indicated by the first segment. Where is A relative to B at the end of that first segment? (ii) We want B to move faster than A and to pass A in a burst of speed. What slope do we need for our new (2nd) segment? (iii) Now, B went so fast he falls down! What kind of slope do we now need so that B does not move for 2 seconds? (iv) A has now caught up and is passing A, and B gets up confused and runs backward! What kind of a segment do I need now? (v) Finally, B gets an amazing burst of energy and finishes the race in a tie! How should I make my last segment? (This raises the issue of what a "tie" means graphically, etc.) Finally, the teacher runs the race and narrates it at the same time, to model what the students will be doing.

(2) Aggregation & Display of Student Constructions, Systematically Varied-Based on Classroom Structure

Here the broad goal of this very general application of classroom connectivity is to generate and examine important mathematical structures and relationships, and to elevate the abstraction-level of mathematical attention from individual constructions to publicly displayed aggregates of these. The underlying idea is to engage students, or groups of students, in building mathematical objects that systematically vary in ways that depend on their place in the social (and perhaps physical) space of the classroom, and then to upload and aggregate these in a common classroom display. One obvious example is the elevation from functions to parametrically varying families of functions. While this vertical flexibility is a powerful pedagogical resource not only for supporting abstraction to parametrized families of objects but for many more general purposes, we will offer only a basic pair of examples.

A Flexible and Generative Group Structure for the Class

Typically, the class is subdivided into groups, where the size of the group is determined by the teacher or activity designer to fit both the given size of the class and the mathematical activity (so the group might simply be the whole class, or each group might have only two members, meaning students are organized in pairs). Then the students count-off inside the group. In this way, each student has a two-number identity that then serves as the value of a "personal parameter" that thus systematically varies across students. The students then create mathematical objects that depend in some critical way on their respective parameter values and then upload these to the teacher where they are aggregated and displayed to the class. Sometimes important variation occurs within a group and sometimes across groups, depending on the activity designer's learning objective and how (s)he chooses to tap into students' identities (e.g., as colleagues, classmates, friends, fellow-sufferers, etc.) Moreover, if members of a group are physically adjacent, then varying the count-off number allows students to see the variation in their group's productions. On the other hand, if we vary group number and not the count-off number, then group members are creating the same object and can help each other, be part of a team, etc. Again, choice of which to vary depends on the goals of the activity.

We will assume for our examples that students are formed into groups with 3-5 members, so each student has a count-off number ranging from 1 to 5, and the number of groups will depend on the size of the class, say 24 in this case.

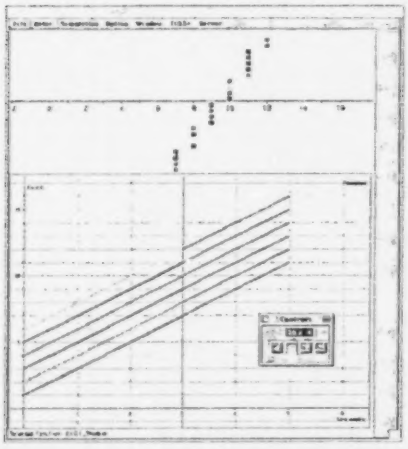

Figure 3.

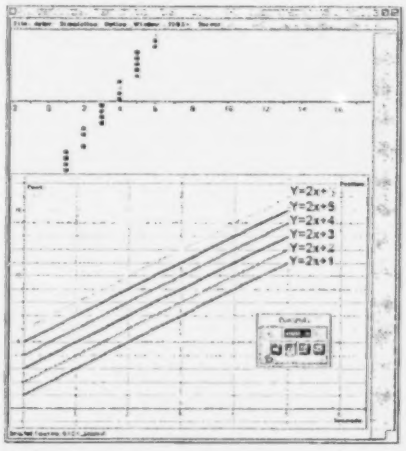

Figure 4.

Linear Functions—The "Staggered-Start, Staggered Finish Race" (varying "b" in y=mX+b)

In the simplest cases, students make a linear position vs. time Y=mX+b function where either m or b is their count-off number. In the latter, they make a 2 ft/sec motion defined by the position vs. time function Y=2X+b where "b" is their count-off number. We give Y=2X as a reference point. (Nobody has count-off number zero, although we can make activities where students subtract, say 3, from their count-off number, so someone gets to have parameter value equal to zero.) The resulting set of parallel lines and staggered starting points help reveal the invariance of slope (2 in this case), and how the systematically varying y-intercept relates to initial position. A companion activity involves using their group number as a starting point, so everyone in a group travels side-by-side, as shown in Figure 3, where we see the screen after 3 seconds of the 5 second race, and all persons in a group travel together. Furthermore, the position vs. time graphs of a given group are coincident, while the respective graphs of the 6 groups are all parallel. Lastly, in Figure 4 we can see the equation of each function and hence the parametric variation reflected in the seven values of "b" in y = 2X+b

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Linear Functions—The "Staggered-Start, *Simultaneous* Finish Race"

In this activity, one dot (A) starts at 0 m and travels at 2 m/sec for 6 seconds. Each student starts at 3 times their group number and is to finish in a tie with A. Here each student in a group is solving the same problem, but may do so in many different ways. Furthermore, since the group numbers vary from 1 to 6, the starting points vary from 3 to 18, which means that the slopes of the graphs (see Figure 5) vary from positive, through 0, to negative, with all members of a group traveling together. The coefficients of X vary, along with b, descending by 1.5 as Group number increases from 1 to 6. Group 4, interestingly, starts at the "finish line" (3*4 = 12), has zero velocity, has X coefficient of 0, and has formula Y= 0X+12. This strongly contextualizes Y=12 in a family of functions in 3 ways—algebraically, graphically and in terms of motion (where slope as rate of change is likewise in a central role). Groups 5 & 6 move backwards!

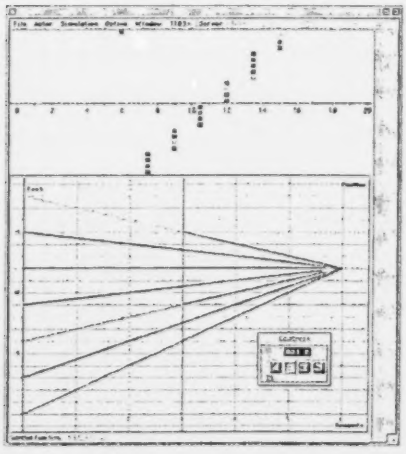

Figure 5.

(3) The *Where Am I?* Aggregation Activity Structure

In this genre of activities, both group and count-off numbers typically are allowed to vary, so each student in the class produces and sends up a unique object. However, the display of the aggregate is deliberately ambiguated to put the student in the position of needing to focus and reason in generally predictable ways to "find themselves" in the common display. We see two sources of pedagogical power in this type of activity: (1) The control of mathematical focus and reasoning based on the specific design of the activity (usually through the variation of representational elements), and (2) The engagement of the student's personal identity at the mathematical heart of the activity via the student's personal projection of their identity into the publicly visible display – students and their peers quickly come to refer to the objects as directly indexing the members of the class, referring to a dot via a person's name, rather than indirectly (e.g, using phrases such as "John is ahead of Mary," or "Is that you?" rather than indirect references such as "John's dot is ahead of Mary's dot," or "Is that your dot?"

Our repeated experience with this activity structure convinces us that it has enormous power to energize a class, to focus students' attention on specific and important mathematical relationships and infuse it with affect based on the fact that students'

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personal identity is projected into the shared public space . We offer a simple example with linear functions.

Linear Functions—Varying Starting Position (Group Number) and Velocity (Count-off Number)A

Start at your group number & go for 5 seconds at a velocity (whose numeric value is) equal to your count-off number.

(a) Which graph is yours? Explain your reasoning. (See Figure 6.)

(b) Based on *your motion only*, Where Are You? Explain your reasoning. (See Figure7.)

(c) Which formula is yours? Explain your reasoning. (A list of all possible formulas is shown.)

In versions (a) and (c), respectively, students must relate the given initial position and velocity information to vertical intercept and slope of the graphs, or the constants in the formulas. In (b) they must relate the given initial position and velocity information to the motion, with the graphs hidden. Note that the teacher

has control of what information that is made visible to the students, hence can hide the graphs. In figure 6, we have displayed all the functions and representational elements simultaneously. However, we could display the motion with "Marks" dropped on a per-second basis, as shown Figure 7.

In Figure 6, we included an "outlier." The potential role of errors is enhanced, as is the potential for student embarrassment—hence the teacher has the option of hiding any functions she chooses. We have seen great excitement and excellent logical reasoning occur as students attempt to track down the author of an erroneously produced object.

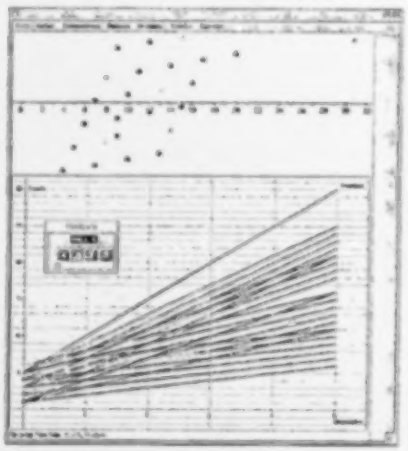

Figure 6.

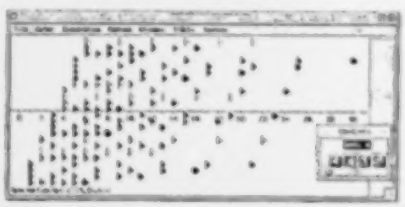

Figure 7.

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Results and Conclusion: What Are We Learning?

A pre/post-test comparison for a 15 hour intervention with grade 7-9 students that applied the above activity structures as well as others involving simultaneous equations showed strongly significant gains on a battery of items drawn from a rigorous state 10th grade examination. Two thirds of the students were 9th graders who had previously failed or nearly failed the 8th grade version of the test a year earlier and the remaining students were 7th and 8th grade volunteers. All students gained on almost all items, and statistically strong gains summed across items for each of the groups. Of special note were strong gains on open-ended modeling items which most students find especially difficult.

We are in the very earliest stages of applying classroom connectivity and the illustrations offered above barely scratch the surface of what we foresee. As noted in Stroup, et al. (These Proceedings), the relationship between mathematical and classroom social structure has been radically strengthened, as has the potential for engaging aspects of students' identity and personality. Not only are our traditional expectations regarding classroom technology use being challenged, but our theories and accounts of teaching and learning are being challenged as well.

Note

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